

# **MHD Modeling and Experiments at UCLA for the ITER Test Blanket Program**

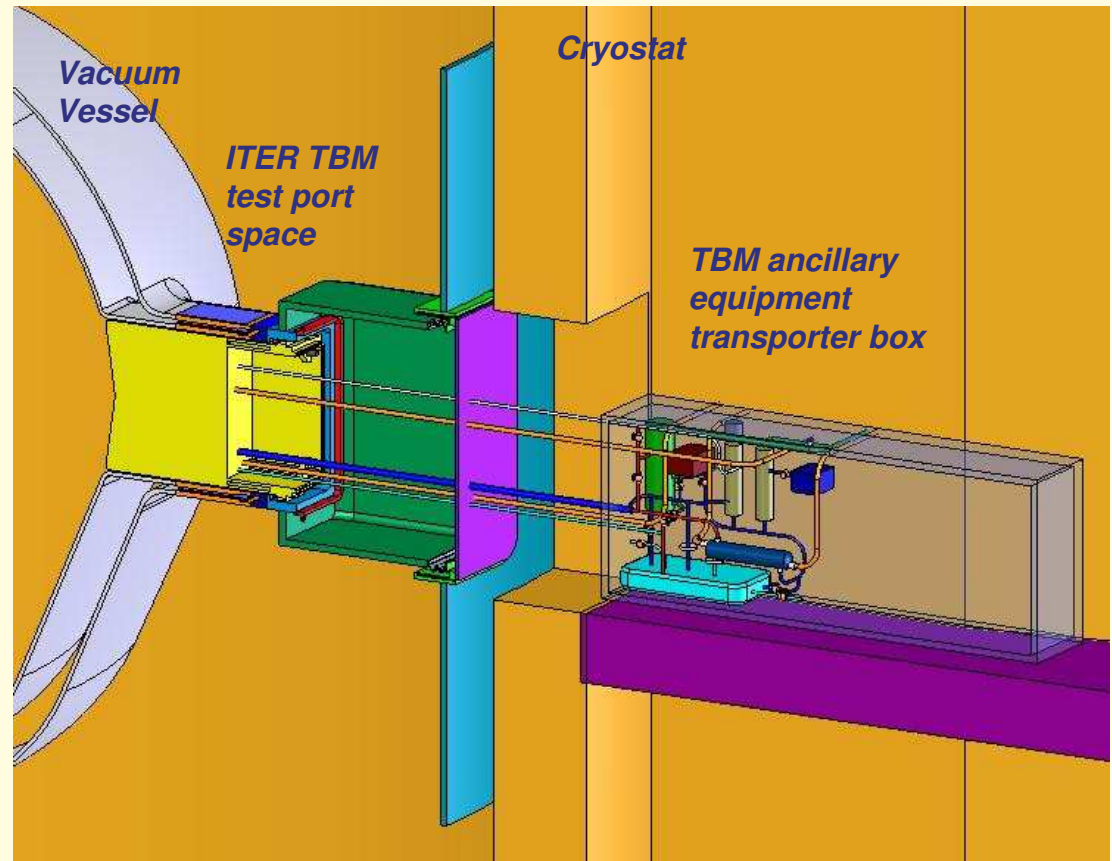
N. Morley, M. Abdou, A. Ying,  
S. Smolentsev, M-J. Ni, T. Sketchley,  
J. Burris, M. Narula

PFC Meeting, PPPL, May 9-11, 2005

# What is the ITER Test Blanket Module (TBM) Program?

*Integrated experiments on first wall and breeding blanket components and materials in a Fusion Environment*

- ❑ Integrated First wall Breeding Blankets will be tested in ITER, starting from **Day One**, by inserting Test Blanket Modules (TBMs) in specially designed ports.
- ❑ Each TBM will have dedicated systems for tritium heat extraction, diagnostics etc.
- ❑ ITER's construction plan includes specifications for TBMs because of impacts on space, vacuum vessel, remote maintenance, ancillary equipment, safety, availability, etc.
- ❑ Overlap between TBM and Module 18, Diagnostic Port Plugs, Tritium Systems, etc.



# US Selected Options for ITER TBM

*The conclusion of the US community, based on the results of a technical assessment of the available data and analyses to date, is to select two blanket concepts for the US ITER-TBM with the following emphases:*

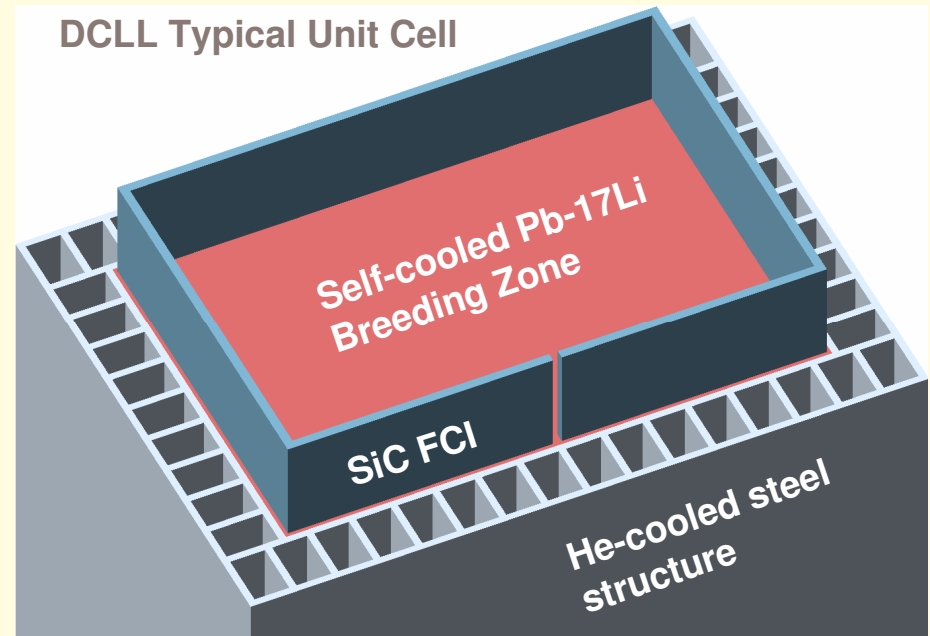
- ❑ A **helium-cooled solid breeder** (pebble bed) concept with ferritic steel FW heat sink and structure and beryllium PFM and neutron multiplier
  - All parties are interested in solid breeder as the nearest term option
  - Support EU and Japan efforts using their TBM structure and ancillary equipment
  - Contribute only unit cell and sub-module test articles that focus on particular technical issues of US expertise and of interest to all parties.
  
- ❑ A **Dual-Coolant Pb-Li liquid breeder** blanket concept with helium-cooled ferritic steel FW heat sink and structure and self-cooled LiPb breeding zone separated by flow channel inserts (FCIs) as MHD and thermal insulator
  - Most parties are interested in Pb-Li as a liquid breeder, especially EU and China. Explore possibility of joint research and development programs.
  - Develop and test FCI in the US
  - Plan an independent TBM that will occupy half an ITER test port with corresponding ancillary equipment.

# Dual Coolant Lead-Lithium (DCLL) FW/Blanket Concept

*Idea of “Dual Coolant” concept –  
Push towards higher  
performance with present  
generation materials*

- ❑ Ferritic steel first wall and structure cooled with helium
- ❑ Breeding zone is self-cooled Pb-17Li
- ❑ Structure and Breeding zone separated by SiCf/SiC composite *flow channel inserts (FCIs)* that
  - ❖ Provide thermal insulation to decouple Pb-17Li bulk flow temperature from ferritic steel wall
  - ❖ Provide electrical insulation to reduce MHD pressure drop in the flowing liquid metal

*Pb-17Li exit temperature can be significantly higher than the  
operating temperature of the steel structure ⇒ High Efficiency*



# ARIES Dual Coolant Design (FED, 65, 2003)

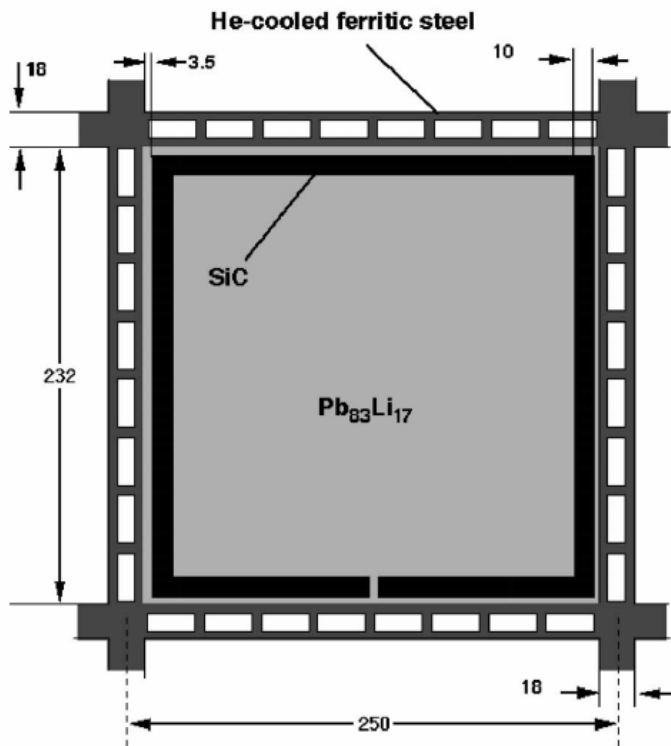


Fig. 8. Cross section of the breeder region unit cell.

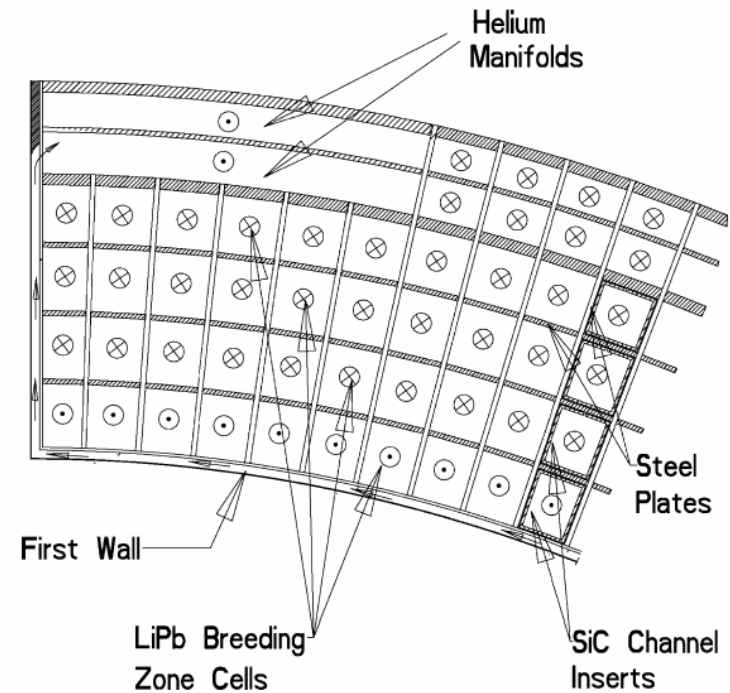


Fig. 6. Detail of blanket cross-section.

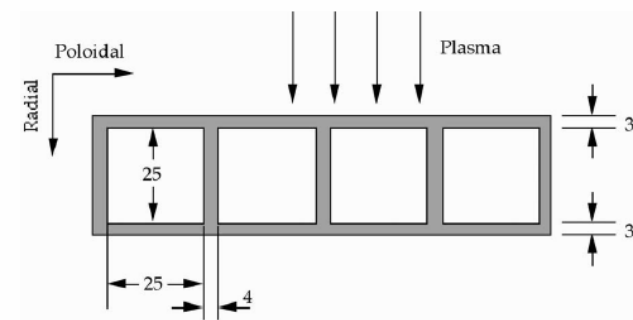
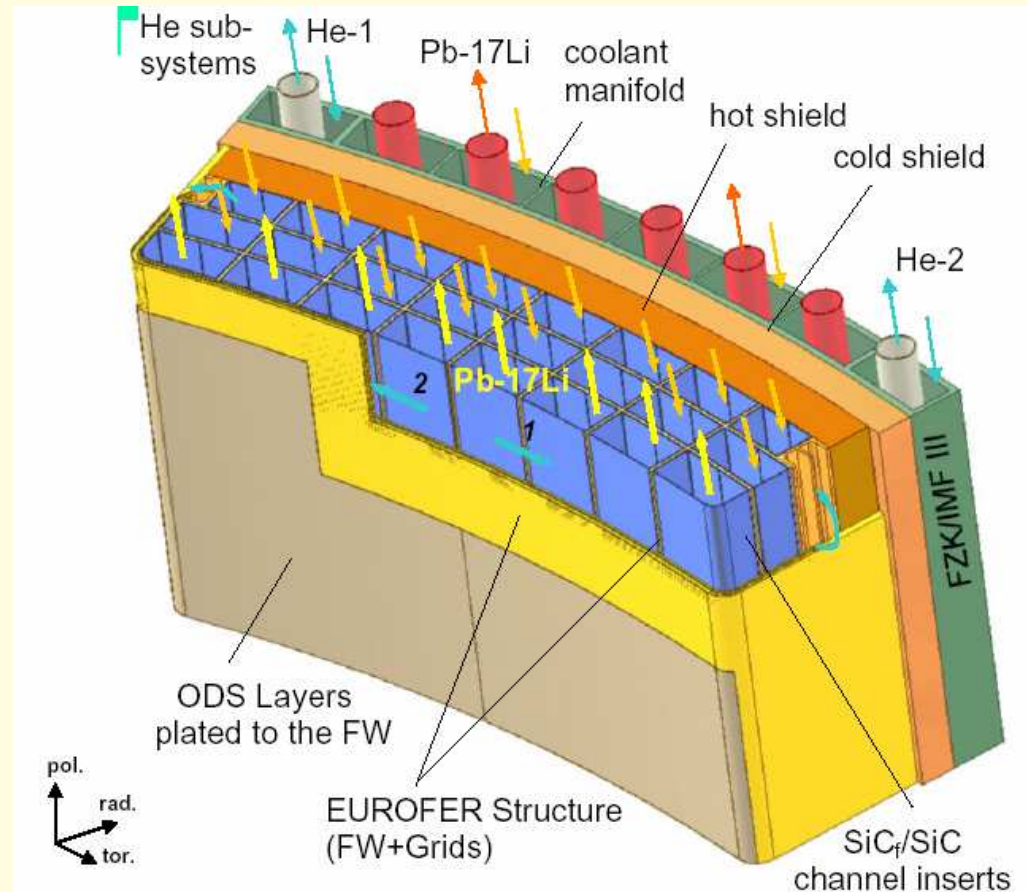
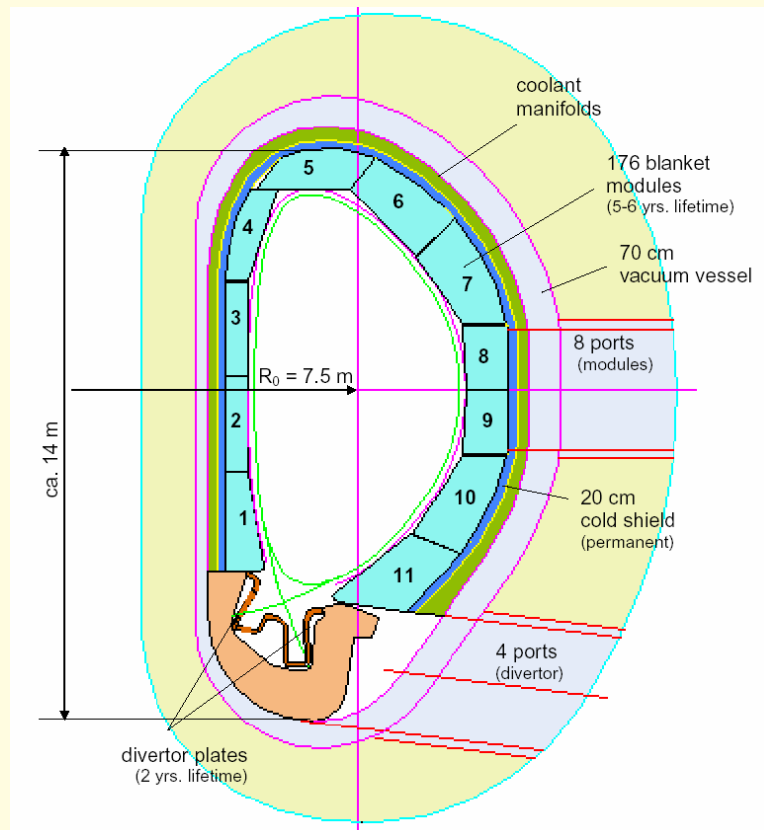


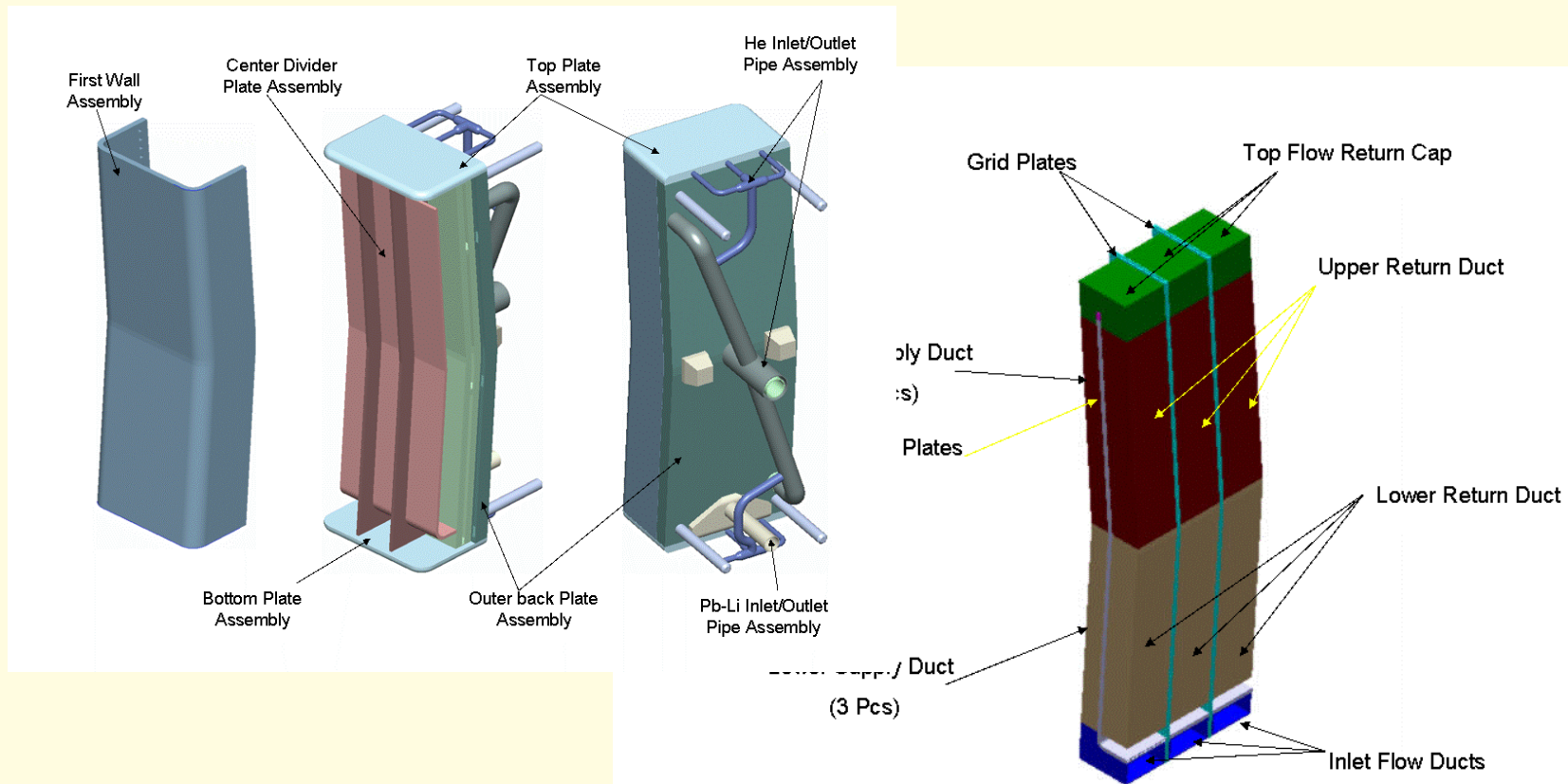
Fig. 7. Cross section of the first wall box.

# EU Advanced Dual Coolant DEMO Blanket (FED, 61-62, 2002 or FZKA 6780)





# US DCLL TBM Designs evolved this year



***Dual Coolant Lead-Lithium TBM Views showing complete structure (left), and internal channel FCIs (right)***

## Interesting MHD issues for self-cooled liquid metal breeding regions

- ❑ **MHD Pressure drop** is a serious concern for inboard LM blankets in high field, high power density reactors Even moderate, but non-uniform, MHD pressure drops (arising from flaws for example) can seriously affect **flow balance between parallel channels** leading to hot channels
- ❑ **MHD velocities profiles** can exhibit strong jets next to regions of stagnation and even reversed flow
- ❑ Large temperature gradients can drive **natural convection** flows that MHD effects do not damp – can swamp forced flow velocity in slow moving breeder zone regions
- ❑ **Turbulence/stability modification** and suppression by MHD forces and joule dissipation will likely affect performance
- ❑ *All of these MHD issues strongly influence heat transfer, corrosion, tritium permeation and ultimate design and selection of LM-facing materials*



# **Flow Channel Insert properties and failures critically affect thermofluid MHD performance potential**

- ❑ **Electrical and thermal conductivity of the SiC/SiC perpendicular to the wall (i.e. weave in 2D composites) should be as low as possible**
- ❑ **The inserts have to be compatible with Pb-17Li at temperatures up to ~800 °C**
- ❑ **Liquid metal must not “soak” into pores of the composite (or foam) in order to avoid increased electrical conductivity. In general, closed porosity and/or dense SiC layers are required on all surfaces of the inserts.**
- ❑ **Secondary stresses caused by temperature gradients must not endanger the integrity of irradiated FCIs.**
- ❑ **The insert shapes needed for various flow elements must be fabricable – basic box-channel element**

# **MHD research needed for DCLL TBM shares resources with ALIST module B**

- ❑ Since beginning of APEX/ALPS, MHD research in PFC and Plasma Chamber have been combined.
  - MHD capability in the US has remained strong over due to the free surface effort under APEX and ALPS and SBIR investment
- ❑ In FY05 the DCLL TBM MHD work was relatively small to scope out issues for DCLL design – in upcoming year competition for resources will be more serious
- ❑ MHD aspects of DCLL are critical to detailed TBM design & performance, as well as being a key issue for testing in ITER.
- ❑ MHD research represents an area where the US has both expertise and unique capabilities
  - contribute to TBMs of US and ITER parties considering various PbLi systems
  - gain in return data on ferritic steel fabrication, tritium removal systems, PbLi chemistry control and corrosion, etc.

# UCLA effort on MHD simulation of DCLL

- ❑ Development of specific 2D and quasi 3D MHD research codes for given phenomena and geometries of interest
  - Straight channels with multimaterials (LM/FCI/Wall) and multi-channels
  - Natural convection / 2D turbulence
  - Coaxial supply / return channels

These codes being used to investigate phenomena, analyze evolving TBM designs, evaluate needed properties from SiC, and provide benchmark for full 3D codes

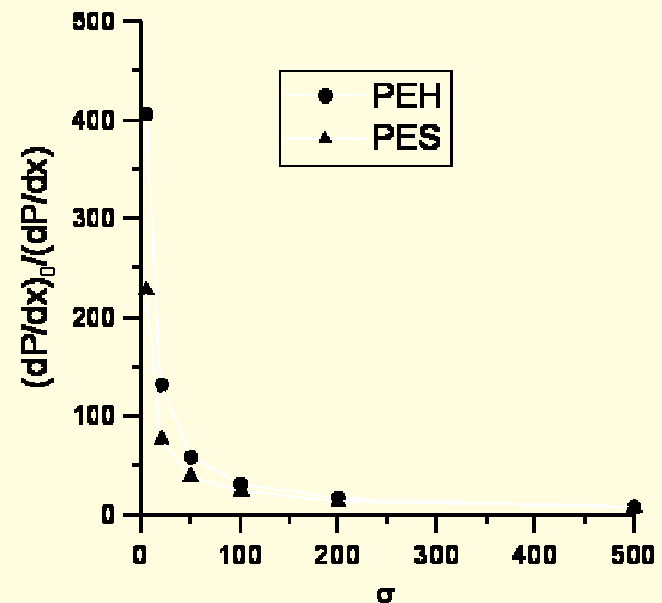
- ❑ Continue development and application of 3D-HIMAG in complex geometry multi-materials at high Hartmann No. (Hypercomp and UCLA)
  - Fully developed straight channels with multi-materials
  - High Hartmann no. models and formulations
  - Benchmarking
  - Manifolds and flow balancing



# Imperfections in FCIs and design of complex flow elements will dominate pressure drop

- Primary issue for blanket application and ITER testing is the MHD pressure and flow distribution for complex geometry flow elements:

- SiC FCI overlap regions (stovepiping)
- Defects in FCIs
- Flow balancing (passive and active)
- Turns in poloidal plane
- Toroidal to poloidal turns
- Field entrance/exit regions
- Radial to toroidal manifolds
- Contractions/expansions in poloidal plane
- Coaxial Pb-Li supply/return lines

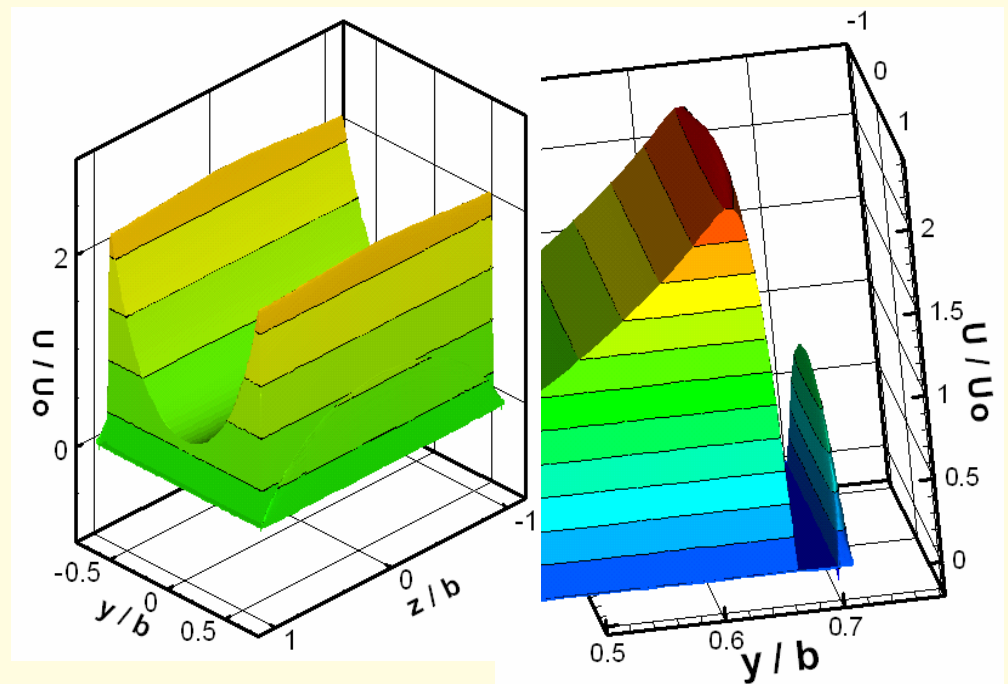


$(dP/dx)_0$  is the MHD pressure drop without FCI

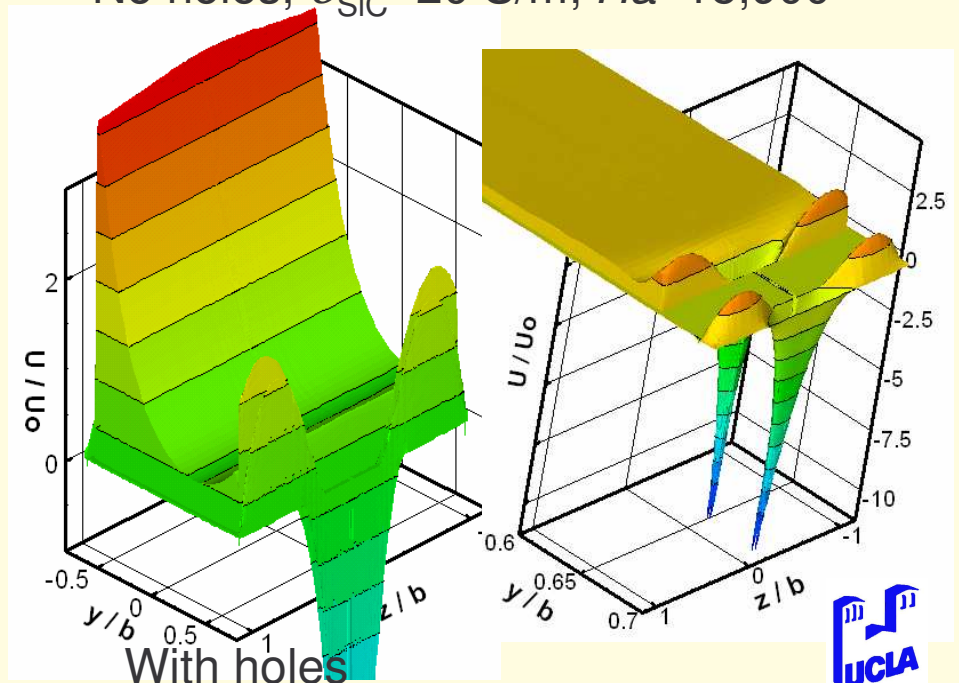
- Experimental validation will be required for many flow elements – the need will be determined this year.

## Strong effects on velocity jets seen near FCI pressure equalization holes or unintentional flaws

- ❑ Large negative jets are seen near pressure equalization holes on side walls parallel to the field
- ❑ Reverse jets can be very large, 10 x average velocity or more depending on conductivity of the SiC



No holes,  $\sigma_{\text{SiC}}=20 \text{ S/m}$ ;  $Ha=15,900$



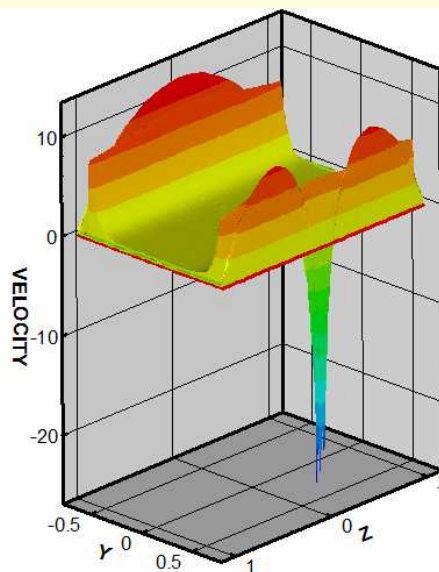
With holes

# Size of velocity jets sensitive to SiC conductivity parallel to surface dominate influence on

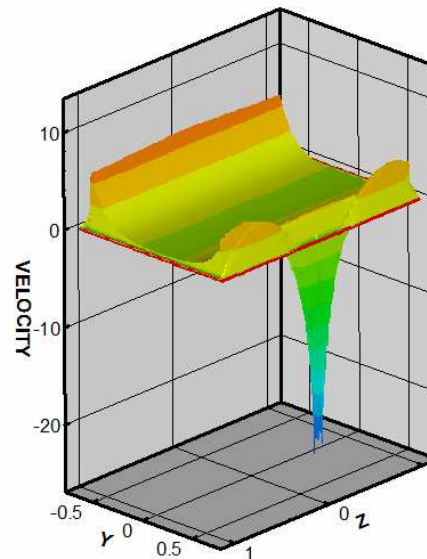
- ❑  $\sigma_{\text{SiC}}$  needs to be reduced to about 5 S/m to eliminate large jets
- ❑ Velocity profile affect heat transfer, corrosion, and tritium concentration

- ❑ New data shows  $\sigma$  perp to be 100x lower than  $\sigma$  parallel, ~2-5 S/m over temp range

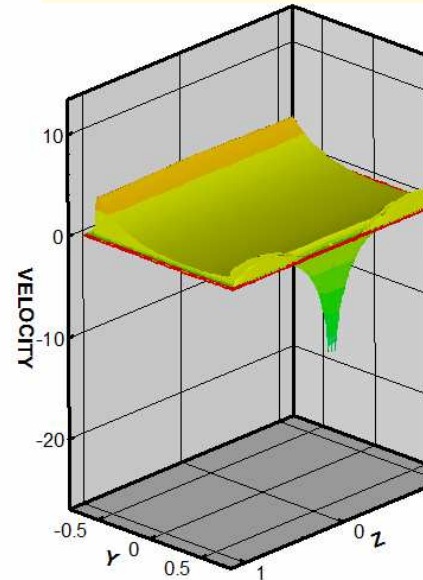
$\sigma=500 \text{ 1/Ohm-m}$



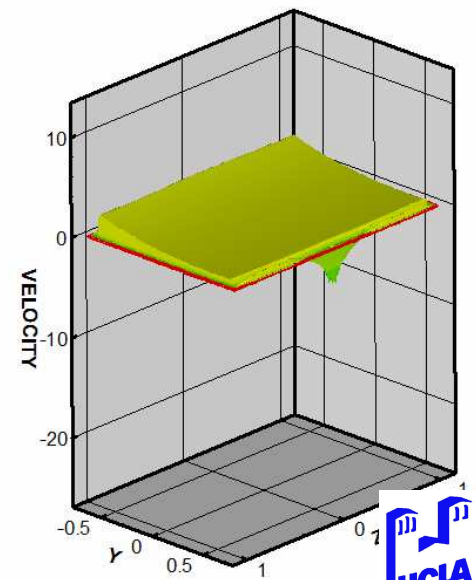
100



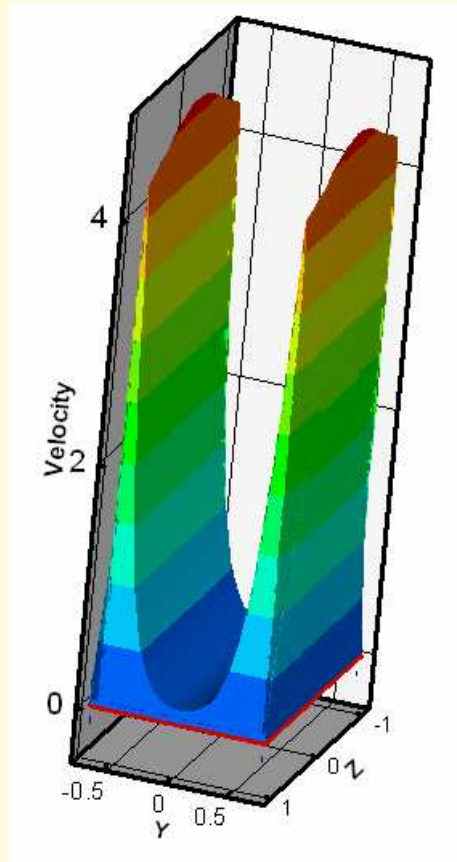
20



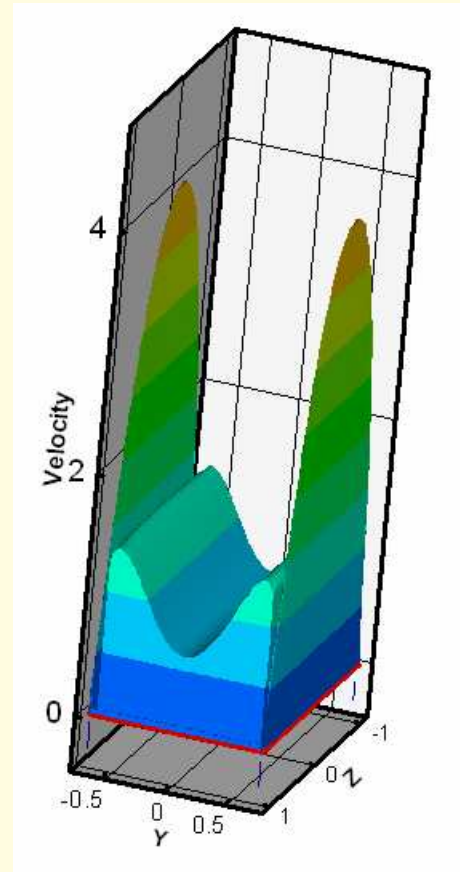
5



## Jet instability and 2D Turbulence generation affect jet width and transport properties



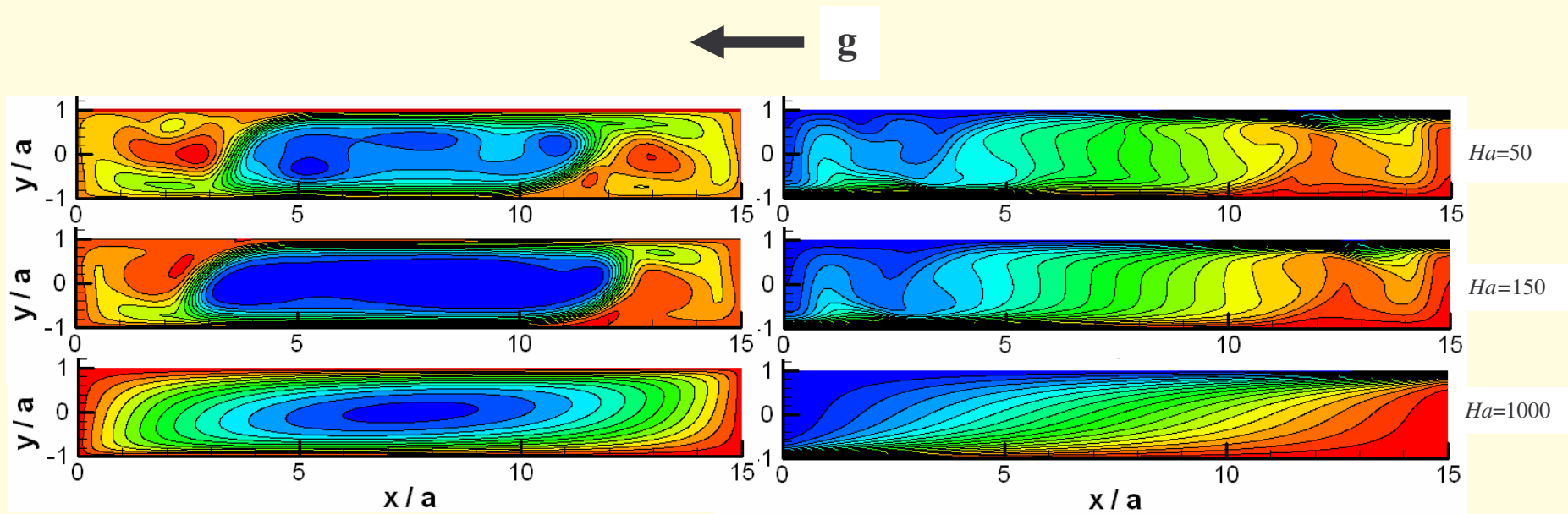
Fully developed flow in the poloidal channel of the DCLL blanket



The turbulence is introduced with a newly developed zero-equation model for anisotropic 2-D MHD turbulence.



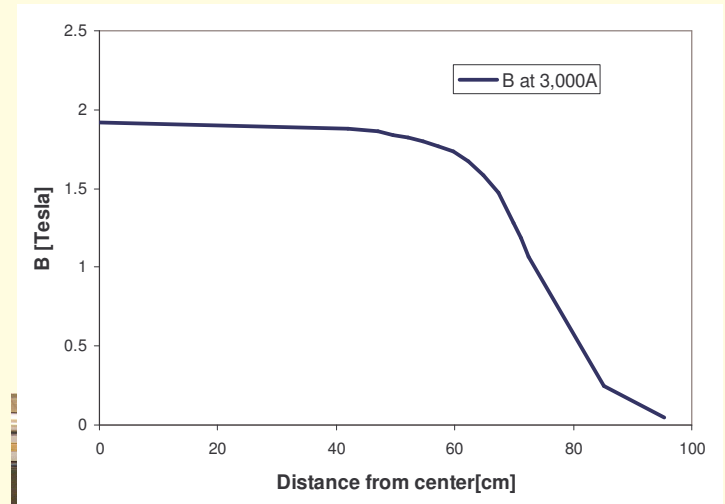
# Coupling to temperature field results in strong natural convection phenomena



Natural convection in the presence of a magnetic field: stream function (left) and isotherms (right).  $Gr=0.5 \times 10^7$ ,  $Pr=0.025$ . “Hot” wall is  $y/a=-1$ . The magnetic field reduces the effect of natural convection. In the blanket conditions, natural convection will not be fully suppressed.

# MHD experiments in MTOR at UCLA

- ❑ Initial DCLL MHD experiments with existing gallium alloy loop needed in FY06 timeframe.
  - Testing SiC compatibility with Ga alloy in RT to 100 C range (underway)
  - Adaptation of MTOR Ga loop for 150C operation
  - Straight channels with FCI joint and heat transfer (FCI from SBIR in ~1 yr time frame)
  - Series of MHD experiments on manifolds and contraction/expansion – investigate flow distribution and control (>1 yr time frame)
  
- ❑ MHD/Corrosion/Compatibility experiments with PbLi loop
  - Designing of high temperature PbLi loop (this year)
  - Loop construction and testing
  - Prototypic PbLi interactions and corrosion testing in tandem with high temperature MHD / heat transfer



# Initial results of Gallium alloy and SiC compatibility tests at 100 C show no wetting – FCI MHD experiments using Ga appear possible

- ❑ 1 cm diameter CVD SiC disk was cut in half by diamond saw
- ❑ 1 half was clamped in a 304 SS holder and immersed in 15 ml of Ga-In-Sn alloy in a Pyrex graduated cylinder
- ❑ Assembly was held at 100°C for 147 hours
- ❑ No wetting on either as-received or machined surface observed, sample cleaned with Qtip to remove little adhered LM
- ❑ No weight change from initial 350 mg within 1 mg resolution



## **TBM needs and schedule is still evolving**

- ❑ ITER Design Description Document nearing completion
  - main task in FY05
- ❑ R&D tasks, schedule and cost being analyzed in US program over the summer
- ❑ Negotiations continuing with parties intending to test liquid metal systems